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Human Health Risk Assessment Arsenic in Drinking Water, Dover Air Force Base, Delaware (AMC)

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A human health risk assessment (HHRA) of arsenic was completed for Dover AFB. The purpose of this assessment is to quantify risks to military personnel and their families living on Dover AFB ingesting base supplied water with elevated levels of arsenic. The base drinking water system is supplied by ground water that contains arsenic. The level of arsenic has always been below the SDWA standard. Sample data were analyzed for potential health effects to the exposed population. Sample results were statistically reviewed and risk estimates were calculated. This health risk assessment evaluated both cancer and non-cancer end points. Non-cancer effects are considered negligible. Some of the risk values are above the acceptable range considered safe by the USEPA. These risk estimates are based on very conservative estimates of exposure and toxicity and are likely to overestimate the actual risk. If we focus on the arsenic level within distribution system (tap water) for RME consuming 2 liters per day for an adult and 1 liter per day for a child, the risks fall slightly above the "de minimis" risk level of 1.0E-06. The drinking water is considered safe as legally defined as "acceptable risk" because the system meets compliance with the SDWA.

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EXECUTIVE SUMMARY

A human health risk assessment (HHRA) of arsenic was completed for Dover Air Force Base (Dover AFB). The purpose of this assessment is to quantify risks to military personnel and their families living on Dover AFB ingesting base supplied water with elevated levels of arsenic. HQ AMC/SGPB supported the base bioenvironmental engineer's request for AFIERA to perform a HHRA.

Dover AFB is located two miles south of the city of Dover (state capitol). It is home to the 436th Airlift Wing, known as the "Eagle Wing" and the 512th Airlift Wing, the Air Force Reserve associate. Dover AFB has responsibility for supplying safe drinking water as defined by the US Environmental Protection Agency (USEPA) Safe Drinking Water Act (SDWA) and monitoring the drinking water for compliance with the SDWA and local and State requirements. Dover AFB is responsible to inform the base populace of any non-compliance status as well as an annual consumer confidence report (CCR) detailing any problems with water quality.

The base drinking water system is supplied by ground water that contains arsenic. The level of arsenic has always been below the SDWA standard. The USEPA proposed to lower the arsenic standard from 50 micro grams per liter (ug/L) to 10 ug/L. With the proposed standard, systems with arsenic levels between 5 – 10 ug/L are required to make educational statements in the annual drinking water consumer confidence reports starting in July 2002. The USEPA recently rescinded the proposed standard of 10 ug/L. The current standard is still 50 ug/L.

Although drinking water samples have been collected at Dover AFB since 1980, the sample data provided was limited with respect to representativeness of the system. Sample data pathways were screened by comparing sample results to the USEPA Region III RBCs (established standards). Since the data were above the screening values, the data were analyzed for potential health effects to the exposed population. Sample results were statistically reviewed and risk estimates were calculated.

This health risk assessment evaluated both cancer and non-cancer end points. Non-cancer effects are considered negligible. Calculated cancer risk for the distribution system ranged from 3.59 E-05 to 1.74 E-04. Some of the risk values are above the acceptable range considered safe by the USEPA. These risk estimates are based on very conservative estimates of exposure and toxicity and are likely to overestimate the actual risk. If we focus on the arsenic level within distribution system (tap water) for RME consuming 2 liters per day for an adult and 1 liter per day for a child, the risks fall slightly above the "de minimis" risk level of 1.0E-06. **The drinking water is considered safe as legally defined as "acceptable risk" because the system meets compliance with the SDWA.**

INTRODUCTION

Purpose

The purpose of this health risk assessment (HRA) is to evaluate arsenic in base drinking water samples collected from the distribution system and a distribution well and quantify risks to military personnel living on Dover Air Force Base (AMC).

Background

Dover AFB is located two miles south of the city of Dover (state capitol) is home to the 436th Airlift Wing, known as the "Eagle Wing" and the 512th Airlift Wing, the Air Force Reserve associate. Dover AFB covers more than 3,900 acres, has two runways, and 1,700 buildings. The base supports 18 tenant units both on and off base. It has an economic impact of more than $470 million on the local economy and ranks as Delaware's third largest industry. There are more than 4,200 military, and 1,200 civilians and 2,500 reservists who work at Dover AFB. The Dover Team's mission is to provide strategic global airlift capability.

The base drinking water system is supplied by ground water that contains arsenic. The level of arsenic has always been below the United States Environmental Protection Agency (USEPA) standard. The USEPA proposed to lower the arsenic standard from 50 micro grams per liter (ug/L) to 10 ug/L. With the proposed standard, systems with arsenic levels between 5 – 10 ug/L are required to make educational statements in the annual drinking water consumer confidence reports starting in July 2002. The USEPA recently rescinded the proposed standard of 10 ug/L. The current standard is still 50 ug/L. The Air Force Environment, Safety and Occupational Health Risk Analysis (AFIERA) Health Risk Assessment Branch (RSRE) was requested to evaluate the potential health risks from ingestion of arsenic in drinking water at current levels.

Arsenic occurs naturally in rocks and soil, water, air, and plants and animals. It can be further released into the environment through natural activities such as volcanic action, erosion of rocks, and forest fires, or through human actions. Approximately 90 percent of industrial arsenic in the U.S. is currently used as a wood preservative, but arsenic is also used in paints, dyes, metals, drugs, soaps, and semi-conductors. Agricultural applications, mining, and smelting also contribute to arsenic releases in the environment.

Higher levels of arsenic tend to be found more in ground water sources than in surface water sources (i.e., lakes and rivers) of drinking water. Compared to the rest of the United States, western states have more systems with arsenic levels greater than 10 ppb. Parts of the Midwest and New England have some systems whose current arsenic levels are greater than 10 ppb, but more systems with arsenic levels that range from 2-10 ppb. While many systems may not have detected arsenic in their drinking water above 10 ppb, there may be geographic "hot spots" with systems that may have higher levels of arsenic than the predicted occurrence for that area.

In most drinking water sources, the inorganic form of arsenic tends to be more predominant than organic forms. Inorganic arsenic in drinking water can exert toxic effects after acute (short-term) or chronic (long-term) exposure. The Safe Drinking Water Act (SDWA) final rule addresses the long-

term, chronic effects of exposure to low concentrations of inorganic arsenic in drinking water. Studies link inorganic arsenic ingestion to a number of health effects. These health effects include:

- Cancerous Effects: skin, bladder, lung, kidney, nasal passages, liver and prostate cancer; and

- Non-cancerous effects: cardiovascular, pulmonary, immunological, neurological and endocrine (*e.g.*, diabetes) effects.

EPA set the current standard of 50 ppb in 1975, based on a Public Health Service standard originally established in 1942. A March 1999 report by the National Academy of Sciences concluded that the current standard does not achieve EPA's goal of protecting public health and should be lowered as soon as possible.

On June 22, 2000, EPA proposed a new drinking water standard of 5 ppb for arsenic and requested comment on options of 3 ppb, 10 ppb and 20 ppb. EPA evaluated over 6,500 pages of comments from 1,100 commenters. Under the Safe Drinking Water Act Amendments of 1996, EPA is required to issue a final rule by January 1, 2001 and Congress subsequently extended this date to June 22, 2001. EPA is setting the new arsenic standard for drinking water at 10 ppb to protect consumers against the effects of long-term, chronic exposure to arsenic in drinking water. Of the approximately 1,100 affected systems, 97 percent are small systems that serve fewer than 10,000 people each. EPA is using its discretionary authority under the 1996 Amendments to the Safe Drinking Water Act to set the standard at a level that "maximizes health risk reduction benefits at a cost that is justified by the benefits."

RISK ASSESSMENT METHODOLOGY

USEPA Risk Assessment Guidance for Superfund (RAGS) was used as the framework for conducting this risk assessment. The USEPA RAGS is based on the National Research Council's four-step risk assessment paradigm which includes evaluating hazard identification, data quality, exposure intake, toxicity, and risk characterization. Our analysis is separated into four distinct phases and includes a discussion on the uncertainty and its effect on the risk estimate. Although these guidance documents have been written to address health risk associated with environmental restoration, the approach is valid to assess exposure, toxicity, and potential risks for other exposure scenarios.

Data Collection and Evaluation

Data collection and evaluation answers the questions of what contaminants are present, where they are present, and in what concentrations. The base Bioenvironmental Engineer, Captain Irshad (436 MDG/SGPB), provided the drinking water sampling data.

The data provided captured 20 years of sampling history for Well D, but only 3 years of data for the base distribution system. The data provided only captured the year collected and a result in parts per billion (ppb). The sample results were screened by comparing them to the USEPA, Region III Risk Based Concentration (RBC) values. Region III RBC values were used because Dover AFB falls under the purview of Region III. The initial screening identified arsenic sample results are above the RBC.

All sample results were evaluated including those below the analytical method detection limits. In accordance with RAGS, sample results indicating less than the sample detection limit were modified to half of the detection value, and samples indicating non-detect were given half of the lowest detection level.

The sample results were statistically analyzed to determine if the data distribution fit better to a normal or log normal distribution. The 95th percent upper confidence limit (95% UCL) was calculated based on the type of best fit. The 95% UCL value was used as the reasonable maximum exposure (RME) concentration to derive risk numbers. The RME is used to be protective; ensuring that high end of intake/dose is captured. Using the RME provides a more conservative estimate of risk. Whenever the 95% UCL exceeded the maximum sample result, the maximum sample result was used as the RME. The central tendency (CT) values were also calculated to derive comparative risk numbers. A summary of the arsenic data in the distribution system and Well D is provided in Table 1.

Table 1. Summary of Arsenic Sample Data

Num	CAS	COPC	RBC	Unit	Max	95% UCL	CT
1	7440382	Arsenic - Distribution System	0.04	μg/L	6.5	6.5	4.7
2	7440382	Arsenic - Well D	0.04	μg/L	19	14.5	11.6

Exposure Assessment

Exposure assessment is the determination or estimation, qualitatively or quantitatively, of the magnitude, frequency, duration, and route of exposure. Exposure is defined as the contact of an organism with a chemical or physical agent.

The exposure assessment is a four-step process:

        Step 1: Characterize the Exposure Setting
        Step 2: Identify Exposure Pathways
        Step 3. Quantify Exposure
        Step 4. Verify Completed Pathway

Step 1: Characterize the Exposure Setting

The exposure setting for this assessment was military and family members residing on base. Water for consumptive use is assumed to be from the base drinking water at the tap. Based on an Air Force assignment study, we assumed that military and family members are assigned at Dover for 13 years (AFIERA, 2000). We assumed a worst case scenario of 350 days per year exposure, which is the USEPA default value (USEPA, 1989). Since this HRA is conservative with respect to approach and calculations, the USEPA default value of 15 days away from the site is used in-lieu of more site-specific data that may be closer to 335 days accounting for annual leave.

Step 2: Identify Exposure Pathways

Domestic uses of water, consumption and bathing/showering, were included in this HRA for possible exposure pathways. The routes of exposure considered were ingestion and dermal absorption from showering. Other pathways from domestic uses of water were not included (e.g. washing clothes, flushing, and cooking). Since Arsenic is a metal, the inhalation route from arsenic escaping the water is eliminated since arsenic will not be in a volatile state.

Step 3. Quantify Exposure

A tiered approach to risk assessment was followed. A simple screening was conducted comparing sample results to RBC values. In some cases, such as potential exposures during showering, the USEPA Region III RBCs were used as input values in USEPA Region IX calculations. This provides more conservative estimate of risk.

In order to quantify exposures, it is necessary to make assumptions and assign values to these assumptions. A USEPA risk assessment usually includes an estimation of intake based on both the average concentration and a concentration correlating to the 95th UCL of the mean. Since the 95th UCL approach is more conservative and likely overestimates risk, it was used to estimate intake.

In the absence of site-specific data, USEPA recommends default values based on scientific studies and professional judgment. Table 2 provides the default exposure values used for the ingestion route. With the exception of the upper limit for drinking water consumption, we have designated each as either a site-specific (SS) value or USEPA default (EPA). Table 3 provides the default exposure values used for dermal exposure. Dermal exposure is based on skin surface area.

Table 2. Exposure Parameters for Inhalation and Ingestion

Exposure Scenario	Exposure Pathway	Daily Intake Rate	Exposure Frequency	Exposure Duration	Body Weight
Residential Adult	Ingestion of Potable Water	2 liters (USEPA)	350 days/yr (USEPA)	13 years (SS)	70 kg (USEPA)
Residential Child	Ingestion of Potable Water	1 liter (USEPA)	350 days/yr (USEPA)	13 years (SS)	15 kg (USEPA)

Note: Child exposure duration is divided as 7 years as a child (1 liter) and 6 years as an adult (2 liters).

Table 3. Exposure Parameters for Dermal Absorption (Showering/Bathing)

Exposure Scenario	Exposure Pathway	Skin Surface Area	Bath Duration	Exposure Frequency	Exposure Duration
Residential Adult	Dermal Absorption (Showering)	23000 cm^2 (USEPA)	0.33 hr (USEPA)	350 days/yr (USEPA)	13 years (SS)
Residential Child	Dermal Absorption (Showering)	7200 cm^2 (USEPA)	0.33 hr (USEPA)	350 days/yr (USEPA)	13 years (SS)

Based on the limited scope of this risk assessment, only two equations were used to calculate intake and dose, drinking water ingestion and dermal exposure from showering. Equation 1 is used to calculate the average daily intake from ingestion of contaminants in the drinking water. The exposure assumption values used to calculate the average dose from ingestion of drinking water contaminants are shown in Table 2. The central tendency (CT), or average ingestion rate was assumed to be 2 L/day, with a maximum (RME) ingestion rate of 5 L/day. The average ingestion rate was selected because it is the USEPA default long-term ingestion rate for adults, and is based on the average consumption rate of water for adults performing normal activities. The maximum ingestion rate was selected because it represents an increased consumption of water due to heavy activities and/or increased temperature during the workday.

Equation 1. Residential Exposure – Drinking Water, Ingestion

$$I = CW \times \left(\frac{CR \times EF \times ED}{BW} \right) \times \frac{1}{AT}$$

where:

I	=	intake (mg/kg body weight per day)
CW	=	Chemical concentration in water (ug/L)
CR	=	Contact rate (liters/day)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (usually expressed in years)
BW	=	Body weight (kg)
AT	=	Averaging time (in days; for carcinogens 70 years x 365 days/year, for non-carcinogens ED x 365 days/year)

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Equation 2 is used to calculate the average daily dose resulting from dermal contact with plumbed water. The exposure assumption values used to calculate the average dose from dermal contact with contaminants are shown in Table 3.

Equation 2. Residential Exposure – Drinking Water, Showering -- Dermal

$$AD = CW \times \left(\frac{SA \times pK \times ET \times EF \times ED \times CF}{BW} \right) \times \frac{1}{AT}$$

where:

AD	=	Absorbed Dose (mg/kg body weight per day)
CW	=	Chemical concentration in water (mg/L)
SA	=	Skin surface area available for contact (cm^2)
PK	=	Chemical-specific dermal permeability constant (cm/hr)
ET	=	Exposure time (hours/day)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (usually expressed in years)
CF	=	Volumetric conversion factor for water (1 liter/$1000cm^3$)
BW	=	Body weight (kg)
AT	=	Averaging time (in days; for carcinogens 70 years x 365 days/year, for non-carcinogens ED x 365 days/year)

Step 4. Verify Completed Pathway

The evaluation and verification of the pathway is often difficult, but this assessment takes a simplistic approach for evaluating the exposure pathway. The assumption that military and family members living on base consume base drinking water completes the pathway. No other pathways are being evaluated.

Toxicity Assessment

The toxicity assessment is divided between cancer and non-cancer health effects resulting from exposures. Cancer effects are evaluated using a slope factor and weight-of-evidence and are calculated based on actual exposure duration. It is important to note that the slope factors are based on the understanding that no exposure is risk free and, therefore, is without a health effect threshold. The weight-of-evidence looks at the likelihood of an agent being a human carcinogen. The likelihood is determined by evidence presented in literature from human and laboratory animal data. Each chemical is assigned a classification code from A through E (A – known human carcinogen and E – evidence of noncarcinogenicty). The slope factor quantitatively defines the relationship of dose and response.

Most often, the non-cancer effect compares exposure levels to a reference dose (RfD). The reference dose is further broken down depending on the type of exposure such as oral or inhalation as well as the duration of exposure. The USEPA is often concerned with lifetime exposures and most often uses the chronic RfD values. The chronic RfD is defined as an estimate of a daily exposure level for a human

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population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime.

Studies have linked long-term exposure to arsenic in drinking water to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate. Non-cancer effects of ingesting arsenic include cardiovascular, pulmonary, immunological, neurological, and endocrine (e.g., diabetes) effects. Short-term exposure to high doses of arsenic can cause other adverse health effects, but such effects are unlikely to occur from U.S. public water supplies that are in compliance with the existing arsenic standard of 50 ppb (ATSDR, 1992).

The principal study for determining the health effects of arsenic is a retrospective case-control study showing significant association of consuming high levels of arsenic in drinking water and cancers of liver, lung, and bladder (IRIS, 2001). Another study showed the relationship of ingestion of drinking water with high levels of arsenic to skin cancer (IRIS, 2001). The studies do include low dose groups, but the data from the low dose groups are inconclusive. Based on the high dosage studies, the USEPA classified arsenic as A – a human carcinogen. In both studies, the population that developed cancer was exposed to arsenic at relatively high levels. The Agency for Toxic Substances and Disease Registry (ATSDR) lists 74 studies of significant exposure to inorganic arsenic through oral route. These studies clearly show a the NOAEL for humans to be between 1 – 10 ug of arsenic per kilogram body weight per day (ppb As/kg/day), and adverse health effects (cancer) starting from 9 ppb As/kg/day (ATSDR, 1992).

Assuming that no safety factors are necessary, using 5 ppb As/kg/day as a NOAEL, we can assume that a child weighing 15 kg would be unaffected up to 75 ppb As in the drinking water. However, safety factors are always incorporated. Using their own safety factor, ATSDR assigned a minimal risk level (MRL) of .3 ppb As/kg/day. This allows a 15-kg child to consume water with arsenic at 4.5 ppb. There are regions in the US where the background level of Arsenic is much higher than 4.5 ppb and health risk assessments are not being performed at thousands of affected locations. The actual acceptable level that would not produce adverse health affects remains unclear, as there is continued debate at what the safe level is. The World Health Organization (WHO) established a safe level of 10 ppb of arsenic in drinking water.

Toxicity Values

The toxicity assessment provides information on the potential health effects. The toxicity values are based on oral, dermal, and inhalation exposure pathways. Values for reference doses, reference concentrations, cancer slope and unit risk values have been derived from a variety of sources. The most acceptable and verifiable values are derived from US EPA's Integrated Risk Information System (IRIS).

To be cited in IRIS, there must exist a body of knowledge regarding a given chemical. For non-cancer studies, it is important to have chronic, multigenerational, developmental and reproductive studies. Human data usually take precedence over animal bioassay data. Cancer studies include human epidemiology studies, rodent bioassays, and vitro assays that might shed light on the mode of action for carcinogenesis. Non-verifiability in IRIS is usually due to a deficiency in the scientific data required for making quantitative analyses.

Toxicity values represent "safe" levels of exposure to avoid cancer and non-cancer effects. Region III RBC tables are a compilation of US EPA IRIS and Health Effects Assessment Summary Tables

(HEAST) and recent EPA-NCEA (National Center for Environmental Assessment) provisional toxicity values. Table 4 identifies the weight of evidence characterization of carcinogenicity, toxicity values used, and the source of value.

Risk Characterization

The risk characterization phase integrates information from the other three phases of the risk assessment and forms an overall conclusion about the risk. Steps for quantifying the carcinogenic risk or non-carcinogenic hazard quotient are applied to each exposure pathway and analyzed.

Carcinogenic Effects

For carcinogens, risk estimators are expressed as the excess incremental probability, above background cancer rates, of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The USEPA, within the Superfund Program, has determined the acceptable range of excess cancer to be 1.0 E-04 to 1.0 E-06 (i.e. the probability of one excess cancer in a population between 10,000 to 1,000,000). USEPA guidance assumes a linear dose-response relationship due to the relatively low exposure levels found at Superfund sites; therefore, the slope factor is a constant, and the risk will be directly related to intake. Under this assumption, the linear low-dose equation for a single chemical is described below in equation 3.

Table 4. Toxicity Factors for COPC

Reference Doses and Carcinogenic Potency Slope Factors									
			Sources: I = IRIS E = EPA-NCEA provisional value			H = HEAST A = HEAST Alternate W = Withdrawn from IRIS or HEAST		O = other	
Contaminant	CAS	EPA Cancer Class.	Oral RfDo mg/kg/d	Source of data	Oral Slope Factor CSFo kg·d/mg	Source of data	Inhalation RfDi mg/kg/d	Source of data	Inhalation Slope Factor CSFi kg·d/mg	Source of data
Arsenic (Distribution System)	7440382	A	3.00E-04	I	1.50E+00	I			1.51E+01	I
Arsenic (Well D)	7440382	A	3.00E-04	I	1.50E+00	I			1.51E+01	I

US EPA Cancer Classification Scheme:
A: Human carcinogen: sufficient evidence from epidemiologic studies to support a causal association between exposure and cancer.
Reference Concentration (RfC): An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious non-cancer effects during a lifetime.

Reference Dose (RfD): An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

Cancer Slope Factor (CSF): The slope of the dose-response curve in the low-dose region. When low-dose linearity cannot be assumed, the slope factor is the slope of the straight line from 0 dose (and 0 excess risk) to the dose at 1% excess risk. An upper bound on this slope is usually used instead of the slope itself. The units of the slope factor are usually expressed as 1/(mg/kg-day).

Equation 3. Carcinogenic Risk

$$[\text{Risk} = \text{LADD} \times \text{SF}]$$

Where:

$$\begin{aligned}
\text{Risk} &= \text{A unit-less probability} \\
\text{LADD} &= \text{Lifetime average daily dose over 70 years (mg/kg-day)} \\
\text{SF} &= \text{Slope factor, the carcinogenic toxicity value (mg/kg-day)}^{-1}
\end{aligned}$$

The risk calculated for each chemical of concern is next summed together to generate an estimate of total risk per exposure pathway.

Equation 4. Total Risk

$$[Total\ Risk = Risk_1 + Risk_2 + Risk_3 + ... + Risk_i]$$

Where:

$$\begin{aligned}
\text{Total Risk} &= \text{the total cancer risk, expressed as a unit-less probability} \\
\text{Risk}_i &= \text{the calculated risk for each chemical of concern}
\end{aligned}$$

Noncarcinogenic Effects

The measure used to describe the potential for noncarcinogenic toxicity to occur in an individual is not expressed as a probability, but is a comparison of the exposure (intake) with a reference dose. This ratio of exposure to toxicity is called the noncancer hazard quotient.

Equation 5. Noncarcinogenic Hazard Quotient

$$[\text{Noncancer Hazard Quotient}^* = E/RfD]$$

Where:

$$\begin{aligned}
E &= \text{Exposure level or chronic daily dose (CDD)} \\
RfD &= \text{Reference dose}
\end{aligned}$$

$^*E$ And RfD must be expressed in the same units and represent the same exposure period.

The RfD is the US EPA's preferred oral toxicity value for noncancer effects. It is defined as an estimate of a daily exposure level for the human population, including sensitive subpopulations (with an order of magnitude for uncertainty) that is likely to be without an appreciable risk of deleterious effects during a lifetime. If the exposure level exceeds the toxicity value (ratio greater than 1), there may be some concern for potential adverse health effects. The level of concern does not increase

linearly as the RfD is approached or exceeded because RfDs do not have equal accuracy or precision nor are they based on the same severity of toxic effects.

Similar to calculating total risk, the total potential for noncancer effects is determined by summing the hazard quotients for each chemical of concern, resulting in a hazard index (also described in Exposure Assessment, Step 3).

Equation 6. Hazard Index

$$\left[HI^* = E_1/RfD_1 + E_2/RfD_2 + \ldots + E_i/RfD_i \right]$$

Where:

$E_i =$ Exposure level (or intake) for the ith toxicant

$RfD_i =$ Reference dose for the ith toxicant

*E *And RfD must be expressed in the same units and represent the same exposure period.*

If the hazard index exceeds unity (1), the analyst must closely examine the target organs involved. If different target organs are affected, the hazard index should be recalculated to group those chemicals that may elicit like responses.

Risk Calculations

Using the principles described above, the carcinogenic risks and non-cancer hazard indices were calculated accounting for exposures to drinking water ingestion. The calculation for cancer risk is based on a 13-year exposure, but can be extrapolated to any period since the cancer risk is directly related to intake and duration. For non-cancer effects, the hazard quotient is the same, regardless of duration.

In the Superfund program, USEPA tries to manage risks in the one in ten thousand to one in one million range. Below one in one million, the risk is considered negligible; above one in ten thousand, some action is usually required. The USEPA preference is for risk numbers to be near the more protective end of the range (one in one million). For Dover AFB, the cancer risk estimates for ingestion of arsenic in drinking water is not within the USEPA's target range. Table 4 shows the cancer risks associated with consumption of base drinking water at Dover AFB, for a 13 year duration, for both 2-L/day and 5-L/Day, and comparison of the CT and RME values.

For the purposes of this document, we used toxicity values from the US EPA Region 3 RBC table. This table includes the typical sources that are used for risk assessments (IRIS, NCEA Health Effects Assessment Summary Tables (HEAST) and ATSDR). For non-cancer effects, the RfD, RfC, and MRLs are all derived in approximately the same way: NOAEL (or LOAEL) is determined (preferably from human data, but more usually from animal studies) and is divided by uncertainty factors. These uncertainty factors represent the uncertainty in extrapolating from animals to humans; from a LOAEL to a NOAEL; from subchronic to chronic studies; and to account for sensitive subpopulations. Table 6 summarizes the non-cancer toxicity values for the chemicals of potential concern at Dover AFB.

Table 5a. Summary of Cancer Risks – Distribution System

Summary of Cancer Risks; Arsenic in Drinking water (Distribution System)				
Cancer Risk	**RME**		**CT**	
Exposure Route	*2 Liters/Day*	*5 Liters/Day*	*2 Liters/Day*	*5 Liters/Day*
Adult; Drinking Water -- Ingestion	4.96E-05	1.24E-04	3.59E-05	8.97E-05
Adult - res, Showering - Dermal	3.02E-08	3.02E-08	2.18E-08	2.18E-08
Totals	**4.96E-05**	**1.24E-04**	**3.59E-05**	**8.97E-05**
Exposure Route	*1 Liter/Day*	*2 Liters/Day*	*1 Liter/Day*	*2 Liters/Day*
Child; Drinking Water -- Ingestion, (6 yrs)	5.34E-05	1.07E-04	3.86E-05	7.73E-05
Child - Adult; Drinking Water -- Ingestion, (7 yrs)	2.67E-05	6.68E-05	1.93E-05	0.00E+00
Child - res, Showering - Dermal	4.41E-08	4.41E-08	3.19E-08	3.19E-08
Totals	**8.02E-05**	**1.74E-04**	**5.80E-05**	**7.73E-05**

Table 5b. Summary of Cancer Risks – Well D

Summary of Cancer Risks; Arsenic in Drinking water (Well D)				
Cancer Risk	**RME**		**CT**	
Exposure Route	*2 Liters/Day*	*5 Liters/Day*	*2 Liters/Day*	*5 Liters/Day*
Adult; Drinking Water -- Ingestion	1.03E-04	2.57E-04	8.87E-05	2.22E-04
Adult - res, Showering - Dermal	6.26E-08	6.26E-08	5.40E-08	5.40E-08
Totals	**1.03E-04**	**2.57E-04**	**8.88E-05**	**2.22E-04**
Exposure Route	*1 Liter/Day*	*2 Liters/Day*	*1 Liter/Day*	*2 Liters/Day*
Child; Drinking Water -- Ingestion, (6 yrs)	1.11E-04	2.22E-04	9.56E-05	1.91E-04
Child - Adult; Drinking Water -- Ingestion, (7 yrs)	5.54E-05	1.39E-04	4.78E-05	1.20E-04
Child - res, Showering - Dermal	9.15E-08	9.15E-08	7.89E-08	7.89E-08
Totals	**1.66E-04**	**3.60E-04**	**1.43E-04**	**3.11E-04**

A Hazard Index (HI) was calculated using the traditionally defined RfDs for each chemical. The HI for each exposure route and summed total are less than unity and therefore would not be evaluated any further within the United States. The HI for each exposure route is shown in Table 5.

Table 6a. Systemic Hazard Quotient for Noncancer Risk -- Distribution System

Summary of Noncancer Hazard Indices (Distribution System)		
NonCancer Systemic Hazard Index (HI)	**RME**	**CT**
Exposure Route	*HI*	*HI*
Adult; Drinking Water -- Ingestion	5.57E-08	4.03E-08
Adult; Drinking Water -- Showering, Dermal	2.11E-10	1.53E-10
Totals	**5.59E-08**	**4.04E-08**
Child; Drinking Water -- Ingestion, (6 yrs)	1.30E-07	9.40E-08
Child - Adult; Drinking Water -- Ingestion, (7 yrs)	5.57E-08	4.03E-08
Child - res, Showering - Dermal	3.09E-10	2.23E-10
Totals	**1.86E-07**	**1.35E-07**

Table 6b. Systemic Hazard Quotient for Noncancer Risk -- Well D

Summary of Noncancer Hazard Indices (Well D)		
NonCancer Systemic Hazard Index (HI)	**RME**	**CT**
Exposure Route	*HI*	*HI*
Adult; Drinking Water -- Ingestion	1.16E-07	9.97E-08
Adult; Drinking Water -- Showering, Dermal	4.38E-10	3.78E-10
Totals	**1.16E-07**	**1.00E-07**
Child; Drinking Water -- Ingestion, (6 yrs)	2.70E-07	2.33E-07
Child - Adult; Drinking Water -- Ingestion, (7 yrs)	1.16E-07	9.97E-08
Child - res, Showering - Dermal	6.40E-10	5.53E-10
Totals	**3.86E-07**	**3.33E-07**

UNCERTAINTY

Risk assessments are estimations of what might occur under certain conditions, provided there is both a hazard present and exposure occurs. These estimations are based on data, assumptions, and models that contain inherent uncertainties. Uncertainties may contribute to an overestimation or underestimation of the true risk and decreases confidence in the calculated risk. This section will address the uncertainties present within each of the four-part risk assessment process.

Data Collection and Evaluation

Uncertainty is inherent with environmental sampling due to the uneven distribution of chemicals in the environmental media over space and time. There are also inherent uncertainties associated with the collection, analytical preparation, and measurement of samples. The results reviewed for this report were summary in nature and did not include data packages with holding times, chromatograms, quality control information, or practical quantification limits. For the purposes of this assessment, we must assume that prior reviews have documented the data to be of adequate quality. The uncertainty of this data gap on the outcome of risk is unknown.

The sample data provided does not have sample specific information other than the year collected and result. This contributes to the uncertainty about the relationship of data to exposed population and sources. With such limited data it is nearly impossible to identify potential sources of elevated results.

Based on the USEPA RAGS methodology, the reasonable maximum exposure (RME) concentration is used to derive risk numbers. The RME is used to be protective; ensuring that high end of intake/dose is captured. The actual intake/dose that is received by personnel assigned to Dover AFB is probably somewhere between the mean and RME concentration and therefore using the RME result will overestimate the potential risk.

Exposure Assessment

Water exposure data gaps contribute to the uncertainty of the calculated risk numbers. The actual source of consumptive drinking water is uncertain as many consumers are purchasing bottled drinking water. Others may have some type of home filtration system that will reduce the contaminant level in the drinking water. The primary concern with the data is only having 3 samples for the distribution system collected 2 and 3 years apart (5 year span).

Toxicity Assessment

Toxicity values are based primarily on human and animal studies. The studies provide information on the dose where the lowest observed adverse effect level (LOAEL) or no observed adverse effect level (NOAEL) is generated experimentally in response to a known exposure over a defined period of time. Safety factors are then applied to the LOAEL or NOAEL to yield a reference dose (RfD, oral) or reference concentration (RfC, inhalation) that is considered the safe threshold for human exposure. Safety factors can range from 1 to 10,000, so there can be a large degree of uncertainty about the "safe dose" for humans. In general, these safety factors are protective for sensitive sub-populations and therefore tend to be very conservative. The built in safety factors will most likely result in an overestimation of risk.

DISCUSSION

Data Quality and Sampling

There is concern whether the data quality and quantity sufficiently represents potential exposures. The primary exposure data should be the distribution system as that is what is being received at the tap. The distribution system data only has 3 data points and is insufficient data for statistical confidence.

The data collected thus far does not seem to be representative of 4 quarters. Having seasonal data may provide information about the varying levels of arsenic. Sample collection dates do not indicate a plan was in place to collect samples during the different seasons. Other historical data such as normal background arsenic levels in ground water, rainfall, climate and soil data would also be useful for understanding variations in the arsenic levels in Well D.

The Safe Drinking Water Act (SDWA) is the main federal law that ensures the quality of drinking water and has established standards for drinking water quality. As with most standards, the SDWA emphasizes sound science and risk-based standard setting. As long as a water system meets the SDWA, no further action is typically necessary. The risk assessment process strictly reviews the RBC values and does not consider the SDWA standards. Therefore, this system which currently meets the SDWA requirements, is shown to have a slightly elevated cancer risk above what is commonly considered negligible risk (1 E-06) when the risk is calculated. It is important to understand the USEPA sets SDWA standards based on balancing health, economic feasibility, and best available technology whereas the risk values are based on predicted health effects from interpreting human and animal studies and exposure assumptions.

Exposure and Toxicity

The exposure pathways were not adequately defined and therefore there is a potential of not evaluating all completed pathways. Data was not provided about soil, crops, meat, milk, sediments, and recreational activities. All of these contribute to total exposure. Information about where the meats, milk, and vegetables are procured will determine the significance of this missing data.

It is important to understand that the toxicity values were established to protect the health of the most sensitive populations, for 30-year exposure duration. This health risk assessment for Dover AFB, was defined as being a military member and family population, with a RME time-on-station of 13 years. As with most health impact, the toxicity of chemicals can be highly variable in individuals. Overall physical condition, chemical sensitivities, and diet all play a major role in physiological response to exposure. The risk generated by the toxicity values used is based on chronic long-term exposures. Probabilistic risk assessments are the next step in the tiered risk assessment process. When there is sufficient data, probabilistic risk assessments are a useful tool for characterizing the uncertainties associated with the HRA.

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CONCLUSIONS

A HRA was completed for arsenic exposure via ingesting drinking water to military members and their families living on Dover AFB. USEPA Risk Assessment Guidance for Superfund (RAGS) was used as the framework for conducting this risk assessment. Although this guidance was written to address health risk associated with environmental restoration, the approach is valid to assess exposure, toxicity, and potential risks. This risk assessment evaluated both the carcinogenic and non-carcinogenic health risks to military personnel and their families.

The sample data provided was limited with respect to representativeness of the site. The samples did not capture potential differences due to seasonal variation and there are very few sampling days for the distribution system. Exposure information was provided with the project guidance. When exposure information was not provided, assumptions were made based on USEPA literature, military references, and professional judgement.

Drinking water samples have been collected at Dover AFB since 1980. Sample data pathways were screened by comparing sample results to the USEPA Region III RBCs (established standards). Since the data were above the screening values, the data were analyzed for potential health effects to the exposed population.

The term "de minimis" risk has been associated with the risk number of 10E-06 or less. The USEPA adopted this number and it became the accepted standard for risk assessment with a scientific background. The risks calculated for Dover AFB drinking water distribution system range from 3.59 E-05 to 1.74 E-04. Some of the risk values are above the acceptable range considered safe by the USEPA. These risk estimates are based on very conservative estimates of exposure and toxicity and are likely to overestimate the actual risk. If we focus on the arsenic level within distribution system (tap water) for RME consuming 2 liters per day adult and 1 liter per day child, the risks fall within the acceptable range, but are slightly above the "de minimis" risk level of 1.0E-06. Since the water system is currently in compliance with the SDWA, the water is considered safe.

The calculated risk for the water from Well D ranges from 8.88 E-05 to 3.60 E-04. All but one calculated value are above the acceptable range considered safe by the USEPA. Well D should not be used as the sole source for the base drinking water. Well D can be used to supplement the base drinking water as long as the blended mix meets the USEPA standard. It is recommended that the base identify the source of elevated arsenic in Well D.

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APPENDIX A

SUMMARY OF DATA

A summary of the data is presented in the following tables.

Human Health Risk Assessment
Dover Air Force Base (AMC)

Summary of Dover AFB Arsenic Sample Results

Total Number of Results: **18**
Total Number Exceeding RBC: **18**

Code	Type	Total	> RBC
GP	Grab - Water (Potable)	18	18

Total Number of COPC Analytes: **18**
Total Number Exceeding RBC: **18**

	Adult	Child
Exposure Duration:	13 yrs	13 yrs
Water Consumption:	2 - 5 L	1 - 2 L
Body Weight:	70 kgs	15 kgs
Use other EPA Defaults		

P = Potable Water

		Total									Best
Num	CAS	COPC	Samples	> RBC	Freq	Media	RBC	Unit	Max	95% UCL	CT	Fit
1	7440382	Arsenic - Distribution System	3	3	100%	P	0.04	µg/L	6.5	6.5	4.7	N
2	7440382	Arsenic - Well D	15	15	100%	P	0.04	µg/L	19	14.5	11.6	N

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Summary of Cancer Risks and Noncancer Hazard Indices (Distribution System)

Exposure Route	RME		CT	
	Cancer Risk 2 yrs	NonCancer Systemic Hazard Index HI	Cancer Risk 2 yrs	NonCancer Systemic Hazard Index HI
Adult; Drinking Water -- Ingestion, 2 Liters per Day	4.96E-05	5.57E-08	3.59E-05	4.03E-08
Adult; Drinking Water -- Showering, Dermal	3.02E-08	2.11E-10	2.18E-08	1.53E-10
Totals	**4.96E-05**	**5.59E-08**	**3.59E-05**	**4.04E-08**
Child; Drinking Water -- Ingestion, 1 Liter per Day	5.34E-05	1.30E-07	3.86E-05	9.40E-08
Child; Drinking Water -- Bathing, Dermal	4.41E-08	3.09E-10	3.19E-08	2.23E-10
Totals	**5.35E-05**	**1.30E-07**	**3.87E-05**	**9.42E-08**

Summary of Cancer Risks; Arsenic in Drinking water (Distribution System)

Cancer Risk	RME		CT	
Exposure Route	**2 Liters/Day**	**5 Liters/Day**	**2 Liters/Day**	**5 Liters/Day**
Adult; Drinking Water -- Ingestion	4.96E-05	1.24E-04	3.59E-05	8.97E-05
Adult - res, Showering - Dermal	3.02E-08	3.02E-08	2.18E-08	2.18E-08
Totals	**4.96E-05**	**1.24E-04**	**3.59E-05**	**8.97E-05**
Exposure Route	**1 Liter/Day**	**2 Liters/Day**	**1 Liter/Day**	**2 Liters/Day**
Child; Drinking Water -- Ingestion, (6 yrs)	5.34E-05	1.07E-04	3.86E-05	7.73E-05
Child - Adult; Drinking Water -- Ingestion, (7 yrs)	2.67E-05	6.68E-05	1.93E-05	0.00E+00
Child - res, Showering - Dermal	4.41E-08	4.41E-08	3.19E-08	3.19E-08
Totals	**8.02E-05**	**1.74E-04**	**5.80E-05**	**7.73E-05**

Summary of Noncancer Hazard Indices (Distribution System)

NonCancer Systemic Hazard Index (HI)	RME	CT
Exposure Route	*HI*	*HI*
Adult; Drinking Water -- Ingestion	5.57E-08	4.03E-08
Adult; Drinking Water -- Showering, Dermal	2.11E-10	1.53E-10
Totals	**5.59E-08**	**4.04E-08**
Child; Drinking Water -- Ingestion, (6 yrs)	1.30E-07	9.40E-08
Child - Adult; Drinking Water -- Ingestion, (7 yrs)	5.57E-08	4.03E-08
Child - res, Showering - Dermal	3.09E-10	2.23E-10
Totals	**1.86E-07**	**1.35E-07**

Reference Doses and Carcinogenic Potency Slope Factors

Sources:

I = IRIS
E = EPA-NCEA provisional value
H = HEAST
A = HEAST Alternate
W = Withdrawn from IRIS or HEAST
O = other

Contaminant	CAS	EPA Cancer Class.	Oral RfDo mg/kg/d	Source of data	Oral Slope Factor CSFo kg·d/mg	Source of data	Inhalation RfDi mg/kg/d	Source of data	Inhalation Slope Factor CSFi kg·d/mg	Source of data
Arsenic (Distribution System)	7440382	A	3.00E-04	I	1.50E+00	I			1.51E+01	I
Arsenic (Well D)	7440382	A	3.00E-04	I	1.50E+00	I			1.51E+01	I

APPENDIX B

RISK CALCULATION TABLES

The risk calculations used for this HRA are presented in the following tables.

Human Health Risk Assessment
Dover Air Force Base

Adult Resident Drinking Water Ingestion

Daily Dose (LADD or CDD) = (RME or CT Conc. x IR x EF x ED) / (BW x AT)

Carcinogenic risk = LADD x Slope Factor

Hazard Quotient = CDD / Reference Dose

Contaminant	RME Conc. mg/L	Lifetime Average Daily Dose mg/kg/d	Chronic Daily Dose mg/kg/d	Cancer Slope Factor CSFo kg·d/mg	Refernce Dose RfDo mg/kg/d	Lifetime Cancer Risk	Systemic Hazard Quotient
Arsenic (Distribution System)	6.50E-03	3.31E-05	1.86E-04	1.50E+00	3.00E-04	4.96E-05	5.57E-08
Arsenic (Well D)	1.35E-02	6.86E-05	3.85E-04	1.50E+00	3.00E-04	1.03E-04	1.16E-07

Description	Value	Units	Rationale (Source)
RME Concentration	listed	mg/L	95% Upper Confidence Limit or Maximium Detect Value
Ingestion rate	2	L/d	Site Specific Parameter
Exposure frequency	350	d/y	Site Specific Parameter
Exposure duration	13	y	Site Specific Parameter
Body weight	70	kg	Adult body weight, Convention; (USEPA 1991)
Averaging time	25550	d	Carcinogenic effects; (USEPA 1989)
Averaging time	4550	d	Noncarcinogenic effects; (USEPA 1989)

Contaminant	CT Conc. mg/L	Lifetime Average Daily Dose mg/kg/d	Chronic Daily Dose mg/kg/d	Cancer Slope Factor CSFo kg·d/mg	Refernce Dose RfDo mg/kg/d	Lifetime Cancer Risk	Systemic Hazard Quotient
Arsenic (Distribution System)	4.70E-03	2.39E-05	1.34E-04	1.50E+00	3.00E-04	3.59E-05	4.03E-08
Arsenic (Well D)	1.16E-02	5.92E-05	3.32E-04	1.50E+00	3.00E-04	8.87E-05	9.97E-08

Adult Resident Drinking Water Dermal Contact

Daily Dose (LADD or CDD) = (RME or CT Conc. x SA x pK x ET x EF x ED x 1E-3 L/ml) / (BW x AT)

Carcinogenic risk = LADD x Slope Factor

Hazard Quotient = CDD / Reference Dose

Contaminant	RME Conc. mg/L	Dermal Permeab. Coeff. cm/h	Lifetime Average Daily Dose mg/kg/d	Chronic Daily Dose mg/kg/d	Cancer Slope Factor	Refernce Dose	Lifetime Cancer Risk	Systemic Hazard Quotient
Arsenic (Distribution Syste	6.50E-03	1.00E-03	2.01E-08	7.05E-07	1.50E+00	3.00E-04	3.02E-08	2.11E-10
Arsenic (Well D)	1.35E-02	1.00E-03	4.17E-08	1.46E-06	1.50E+00	3.00E-04	6.26E-08	4.38E-10

Description	Units	Value	Rationale (Source)
RME Concentration	mg/L	listed	95% Upper Confidence Limit or Maximium Detect Value
Dermal Perm Coeff.	cm/h	listed	Table 5-8, Dermal Exposure Assessment (USEPA 1992)
Surface area	cm3	23000	Adult skin surface area, Convention; (USEPA 1991)
Exposure frequency	d/y	365	Site Specific Parameter
Exposure duration	y	2	Site Specific Parameter
Body weight	kg	70	Adult body weight, Convention; (USEPA 1991)
Averaging time carc.	d	25550	Carcinogenic effects; (USEPA 1989)
Averaging time ncarc.	d	730	Noncarcinogenic effects; (USEPA 1989)
Bath duration	h/d	0.33	(USEPA 1992)

Contaminant	CT Conc. mg/L	Dermal Permeab. Coeff. cm/h	Lifetime Average Daily Dose mg/kg/d	Chronic Daily Dose mg/kg/d	Cancer Slope Factor	Refernce Dose	Lifetime Cancer Risk	Systemic Hazard Quotient
Arsenic (Distribution Syste	4.70E-03	1.00E-03	1.46E-08	5.10E-07	1.50E+00	3.00E-04	2.18E-08	1.53E-10
Arsenic (Well D)	1.16E-02	1.00E-03	3.60E-08	1.26E-06	1.50E+00	3.00E-04	5.40E-08	3.78E-10

Child Resident Drinking Water Ingestion

Daily Dose (LADD or CDD) = (RME or CT Conc. x IR x EF x ED) / (BW x AT)

Carcinogenic risk = LADD x Slope Factor

Hazard Quotient = CDD / Reference Dose

Contaminant	RME Conc. mg/L	Lifetime Average Daily Dose mg/kg/d	Chronic Daily Dose mg/kg/d	Cancer Slope Factor CSFo kg·d/mg	Refernce Dose RfDo mg/kg/d	Lifetime Cancer Risk	Systemic Hazard Quotient
Arsenic (Distribution System)	6.50E-03	3.56E-05	4.33E-04	1.50E+00	3.00E-04	5.34E-05	1.30E-07
Arsenic (Well D)	1.35E-02	7.38E-05	8.98E-04	1.50E+00	3.00E-04	1.11E-04	2.70E-07

Description	Units	Value	Rationale (Source)
RME Concentration	mg/L	listed	95% Upper Confidence Limit or Maximum Detect Value
Ingestion rate	L/d	1	Site Specific Parameter
Exposure frequency	d/y	350	Site Specific Parameter
Exposure duration	y	6	Site Specific Parameter
Body weight	kg	15	Adult body weight, Convention; (USEPA 1991)
Averaging time	d	25550	Carcinogenic effects; (USEPA 1989)
Averaging time	d	2100	Noncarcinogenic effects; (USEPA 1989)

Contaminant	CT Conc. mg/L	Lifetime Average Daily Dose mg/kg/d	Chronic Daily Dose mg/kg/d	Cancer Slope Factor CSFo kg·d/mg	Refernce Dose RfDo mg/kg/d	Lifetime Cancer Risk	Systemic Hazard Quotient
Arsenic (Distribution System)	4.70E-03	2.58E-05	3.13E-04	1.50E+00	3.00E-04	3.86E-05	9.40E-08
Arsenic (Well D)	1.16E-02	6.37E-05	7.75E-04	1.50E+00	3.00E-04	9.56E-05	2.33E-07

Child Resident Drinking Water Dermal Contact

Daily Dose (LADD or CDD) = (RME Conc. x SA x PC x CD x EF x ED x 1E-3 l/ml) / (BW x AT)

Carcinogenic risk = LADD x Slope Factor

Hazard Quotient = CDD / Reference Dose

Contaminant	RME Conc. mg/L	Dermal Permeab. Coeff. cm/h	Lifetime Average Daily Dose mg/kg/d	Chronic Daily Dose mg/kg/d	Cancer Slope Factor	Reference Dose	Lifetime Cancer Risk	Systemic Hazard Quotient
Arsenic (Distribution Syste	6.50E-03	1.00E-03	2.94E-08	1.03E-06	1.50E+00	3.00E-04	4.41E-08	3.09E-10
Arsenic (Well D)	1.35E-02	1.00E-03	6.10E-08	2.13E-06	1.50E+00	3.00E-04	9.15E-08	6.40E-10

Description	Value	Units	Rationale (Source)
RME Concentration	listed	mg/L	95% Upper Confidence Limit or Maximum Detect Value
Dermal Perm Coeff.	listed	cm/h	Table 5-8, Dermal Exposure Assessment (USEPA 1992)
Surface area	7200	cm3	Child skin surface area, Convention; (USEPA 1991)
Exposure frequency	365	d/y	Site Specific Parameter
Exposure duration	2	y	Site Specific Parameter
Body weight	15	kg	Child body weight, Convention; (USEPA 1991)
Averaging time carc.	25550	d	Carcinogenic effects; (USEPA 1989)
Averaging time ncarc.	730	d	Noncarcinogenic effects; (USEPA 1989)
Bath duration	0.33	h/d	(USEPA 1992)

Contaminant	CT Conc. mg/L	Dermal Permeab. Coeff. cm/h	Lifetime Average Daily Dose mg/kg/d	Chronic Daily Dose mg/kg/d	Cancer Slope Factor	Reference Dose	Lifetime Cancer Risk	Systemic Hazard Quotient
Arsenic (Distribution Syste	4.70E-03	1.00E-03	2.13E-08	7.44E-07	1.50E+00	3.00E-04	3.19E-08	2.23E-10
Arsenic (Well D)	1.16E-02	1.00E-03	5.26E-08	1.84E-06	1.50E+00	3.00E-04	7.89E-08	5.53E-10

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APPENDIX C

STATISTICAL ANALYSIS DATA

A summary of the statistical analysis is presented in the following tables. The tables presented are representative of all the data sets used for this HRA. Complete data sets are available upon request to AFIERA.

Human Health Risk Assessment
Dover Air Force Base

W Test for Goodness of Fit (Shapiro and Wilk)

Contaminant of Concern: Arsenic - Dover AFB Distribution System

Regulatory Exposure Limit	5
Units of recorded Data (e.g. ppm, mg/m3):	ppb
Number of Samples:	3
Significance Level (α)	0.05

k =	2
d =	5.48
d (m) =	0.3299
W =	1.0000
W(m) =	0.9873

See Tab A7
| Wp(α): | 0.767 |

See Tab A6
| a1 | 0.7071 |
| a2 | 0.0000 |

Descriptive Analysis

		Statistic Name
Mean (M)	4.7	
Standard Error	2.645448922	
Median	4.7	
Mode	#N/A	
Standard Deviation	1.8	
Sample Variance	3.24	
Kurtosis	#DIV/0!	
Skewness	-1.4933E-15	
Range	3.6	
Minimum	2.9	
Maximum	6.5	
Sum	14.1	
Count	3	
Confidence Level(95.0%)	0.065166246	

		Statistic Name
P =	0.95	
n =	3	
Gamma = (g) =	0.95	
z(gamma)=	1.645	
z (P) =	1.645	
k (g, P, n) =	11.639	
t (P,df) = (P,n-1) =	0.071	
Xp =	6.32	
X(gamma) =	6.32	

a =	1 - (z(gam)^2/2(n-1))	0.323614652
b =	z(P)^2 - (z(gamma)^2/2n)	1.8

Totals

	14.1	0	6.48	2	4.4840754	-6.66E-16	0.3298913
	Modified			Modified			
Rank	Plotting	Data		Plotting	ln (Xi)	Yi - M (ln)	(Yi-M)^2
Plotting Position r/(σ+1)	Position	(Xi) ppb	Xi - M	(Xi-M)^2	for Yi	Yi	
r							
1	0.250	25.000	2.9	-1.800	3.24	3.0647	1.0647	-0.430	0.185
2	0.500	50.000	4.7	0.000	0	3.5476	1.5476	0.053	0.003
3	0.750	75.000	6.5	1.800	3.24	3.8718	1.8718	0.377	0.142

NORMAL

	Statistic Name	Xi	Yi	1/ ln Yi	
ppb	S = sample Std Dev =	1.800	0.406	1.50	
ppb	Mean = M =	4.700	1.495	4.46	
ppb	M - S = X (16%)	2.900	1.089	2.97	
ppb	M + S = X (84%)	6.500	1.901	6.69	
ppb	M - t x S / (n^.5) = LCL =	4.626	1.478	4.33	
ppb	M + t x S / (n^.5) = UCL =	4.774	1.511	4.53	
ppb	M + Zp (95%) x S = X (95%)	7.661	2.163	8.70	
ppb	M + k x S = UTL =	25.651	6.222	503.65	
ppb	OEL =	5	5	5	
ppb	Median = Me =	4.70	1.55		
ppb	(M - Me) / S =	0.000	-0.130		

Smaller Test Statistic, (M-Me)/S, implies better distribution Normal or Lognormal

For Normal Distribution, M = Me = Mo (mean = median = mode)

For Lognormal Distribution, mean = median = mode for ln (data) in Nepers

For Lognormal Distribution, Me of data = GM of data [in ppm or mg/m3 = ug/L]

LOGNORMAL

	Statistic Name
[unitless]	= GS
ppb	= GM
ppb	= CX (16%)
ppb	= CX (84%)
ppb	= GLCL
ppb	= GUCL
ppb	= CX (95%)
ppb	= GUTL
ppb	= OEL

Both Normal and Lognormal Distributions appear to fit the data – Conclude best fit for data is Normally Distributed

30

Calculating the Concentration Term
(In accordance with EPA Supplemental Guidance to RAGS)

The concentration term has uncertainity associated with estmating the true average concentration at a site, therefore the 95 percent upper confidence limit (UCL) of the arithmetic mean should be used for this variable. Once calculated, this term will be used to calculate esitmated intake.

Obviously, with more data points, the higher the accuracy of the true mean. It is also important to consider transforming the data to the natural log (ln). Since our data is already transformed when fitting the data, both UCLs are calculated for us below.

Calculating the UCL of the Arithmetic Mean For a Lognormal Distribution	Calculating the UCL of the Arithmetic Mean For a Normal Distribution

$$UCL = e^{(m + 0.5 \, s^*2 + s \, H \, / \, (n-1)-1)}$$

$$UCL = m + t \, (s \, / \, (n^{-1}))$$

Where:

UCL	=	upper confidence Limit	
e	=	constant (base of the natural log, equal to 2.718)	
m	=	mean of the transformed data	
s	=	standard deviation of the transformed data	
H	=	H-Statistic (from table in tab H)	
n	=	number of samples	

Where:

UCL	=	upper confidence Limit
m	=	mean of the untransformed data
s	=	standard deviation of the untransformed data
t	=	Student-t statistic (Calculated)
n	=	number of samples

m	=	1.49		m	=	4.70
s	=	0.41		s	=	1.80
H	=	5.298		t	=	2.92
n	=	3		n	=	3

95 % UCL =	22.169	ppb		95 % UCL =	7.735	ppb

Arsenic - Dover AFB Distribution System

> Conclude the best fit is Normal -- Recommend Using the 95%
> UCL for a Normal Distributionas shown below:
>
> 95 % UCL = 6.500 ppb

* Note: The calculated 95% UCL is always the lowest value of the calculated value and max value.

W Test for Goodness of Fit (Shapiro and Wilk)

Contaminant of Concern: Arsenic - Dover AFB Well D

Regulatory Exposure Limit	5
Units of recorded Data (e.g. ppm, mg/m3)	ppb
Number of Samples	15
Significance Level (α)	0.05

k =	8
d =	231.269333
d̄ (ln) =	2.3942
W =	0.8892
W(ln) =	0.8424

See Tab A7

Wp(α):	0.866

See Tab A6

a_1	0.5359
a_2	0.3325
a_3	0.2412
a_4	0.1707
a_5	0.1099
a_6	0.0539
a_7	0.0000

Descriptive Analysis

Mean (M)	11.52656667
Standard Error	17.88929791
Median	13
Mode	14
Standard Deviation	4.064386558
Sample Variance	16.5192381
Kurtosis	-0.531209887
Skewness	-0.331206659
Range	14
Minimum	5
Maximum	19
Sum	174.4
Count	15
Confidence Level(95.0%)	0.058805198

P =	0.55
n =	15
Gamma = (g) =	0.55
z(gamma) =	1.645
z (P) =	1.645
k (g, P, n) =	2.291
t (P,df) = (P,n-1) =	0.064
Xp =	16.2
X(gamma) =	16.2

$a =$	$1 - (t(\text{gamma})^2/2(n-1))$	0.903373522
$b =$	$z(P)^2 - (z(\text{gamma})^2/n)$	2.5

Data Table

Rank r	Plotting Position r/(n+1)	Modified Plotting Position	Data (Xi) ppb	Xi - M	(Xi-M)^2	Modified Plotting for Yi	ln (Xi) Yi	Yi - M (ln)	(Yi-M)^2
Totals		174.4		0	231.26933		35.73746	-6.66E-15	2.394198
1	0.063	6.250	5	-6.627	43.9127111	3.6094	1.6094	-0.773	0.598
2	0.125	12.500	5	-6.627	43.9127111	3.6094	1.6094	-0.773	0.598
3	0.188	18.750	6.4	-5.227	27.3180444	3.8563	1.8563	-0.526	0.277
4	0.250	25.000	8	-3.627	13.1527111	4.0794	2.0794	-0.303	0.092
5	0.313	31.250	10	-1.627	2.64604444	4.3026	2.3026	-0.080	0.006
6	0.375	37.500	10	-1.627	2.64604444	4.3026	2.3026	-0.080	0.006
7	0.438	43.750	13	1.373	1.88604444	4.5649	2.5649	0.182	0.033
8	0.500	50.000	13	1.373	1.88604444	4.5649	2.5649	0.182	0.033
9	0.553	56.250	14	2.373	5.63271111	4.6391	2.6391	0.257	0.066
10	0.625	62.500	14	2.373	5.63271111	4.6391	2.6391	0.257	0.066
11	0.688	68.750	14	2.373	5.63271111	4.6391	2.6	0.257	0.066
12	0.750	75.000	14	2.373	5.63271111	4.6391	2.6	0.257	0.066
13	0.813	81.250	14	2.373	5.63271111	4.6391	2.6	0.257	0.066
14	0.875	87.500	15	3.373	11.3793778	4.7081	2.7	0.326	0.106
15	0.938	93.750	19	7.373	54.3660444	4.9444	2.9	0.562	0.316

NORMAL / LOGNORMAL

	Statistic Name		Xi	Yi	1 / ln Yi	LOGNORMAL Statistic Name	
ppb	S = sample Std Dev =		4.064	0.414	1.51	= GS	[unitless]
ppb	Mean = M =		11.627	2.382	10.83	= GM	ppb
ppb	M - S = X (16%) =		7.562	1.969	7.16	= GX (16%)	ppb
ppb	M + S = X (84%) =		15.691	2.796	16.38	= GX (84%)	ppb
ppb	M - t x S / (n^.5) = LCL =		11.560	2.376	10.76	= GLCL	ppb
ppb	M + t x S / (n^.5) = UCL =		11.694	2.389	10.91	= GUCL	ppb
ppb	M + Zp (95%) x S = X (95%) =		18.313	3.063	21.39	= GX (95%)	ppb
ppb	M + k x S = UTL =		20.936	3.330	27.93	= GUTL	ppb
ppb	OEL =		5	5	5	= OEL	ppb
ppb	Median = Me =		13.00	2.56			
ppb	(M - Me) / S =		-0.338	-0.441			

Smaller Test Statistic, (M-Me)/S, implies better distribution: Normal or Lognormal

For Normal Distribution, M = Me = Mo (mean = median = mode)

For Lognormal Distribution, mean = median = mode for [ln (data) in Nepers]

For Lognormal Distribution, Me of data = GM of data (in ppm or mg/m3 = ug/L]

Conclude best fit for data is Normally Distributed

Calculating the Concentration Term
(In accordance with EPA Supplemental Guidance to RAGS)

The concentration term has uncertainity associated with estmating the true average concentration at a site, therefore the 95 percent upper confidence limit (UCL) of the arithmetic mean should be used for this variable. Once calculated, this term will be used to calculate esitmated intake.

Obviously, with more data points, the higher the accuracy of the true mean. It is also important to consider transforming the data to the natural log (ln). Since our data is already transformed when fitting the data, both UCLs are calculated for us below.

Calculating the UCL of the Arithmetic Mean For a Lognormal Distribution	Calculating the UCL of the Arithmetic Mean For a Normal Distribution

$$UCL = e^{(m + 0.5 s*2 + s H / (n-1)-1)}$$

$$UCL = m + t \ (s / (n^{-1}))$$

Where:

UCL	=	upper confidence Limit
e	=	constant (base of the natural log, equal to 2.718)
m	=	mean of the transformed data
s	=	standard deviation of the transformed data
H	=	H-Statistic (from table in tab H)
n	=	number of samples

Where:

UCL	=	upper confidence Limit
m	=	mean of the untransformed data
s	=	standard deviation of the untransformed data
t	=	Student-t statistic (Calculated)
n	=	number of samples

m	=	2.38		m	=	11.63
s	=	0.41		s	=	4.06
H	=	1.982		t	=	1.76
n	=	15		n	=	15

95 % UCL = 14.688 ppb	95 % UCL = 13.475 ppb

Arsenic - Dover AFB Well D

Conclude the best fit is Normal -- Recommend Using the 95% UCL for a Normal Distributionas shown below:

95 % UCL = 13.475 ppb

* Note: The calculated 95% UCL is always the lowest value of the calculated value and max value.